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USDA Forest Service
GSDUpdate
Rocky Mountain Research Station
Grassland, Shrubland and Desert Ecosystems Science Program

Strategies for Understanding and Controlling Species Invasions

Invasive species are significant environmental and economic threats to our Nation's and the world's ecosystems and natural resources. They impact wildlife habitat, endanger native species, threaten ecosystem services, damage lakes and rivers, reduce recreational opportunities, affect production of wood products, jeopardize human health and safety and reduce property values. Adverse effects from invasive species can be exacerbated by interactions with fire, native pests, weather events, human actions, and environmental change. Invasive species cause billions of dollars in damage each year. Costs of damage from invasive species worldwide has been estimated to be more than $1.4 trillion per year—5 percent of the global economy.

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Global trade and transportation have facilitated the expansion of many species well beyond their native range, and species introductions have furthered the foothold of exotics. On public lands, the likelihood that invasive species will spread through travel and recreation is increasing as more and more people use forests, grasslands, lakes and streams for purposes ranging from recreation to subsistence.

Many species of invasive plants, insects, pathogens, terrestrial animals, and aquatic organisms have established in forest, grassland, and aquatic ecosystems. Because of the harm caused by invasive species in the United States, combined with the likelihood of new introductions, the USDA Forest Service developed and published a comprehensive approach, known as the *Forest Service National Strategic Framework for Invasive Species Management* (2013, FS-1017) to guide current and future management activities for reducing undesirable impacts. The Research and Development branch of the Forest Service plays an important role in addressing framework strategies by developing knowledge to prevent, detect, control and manage invasive species, and restore and rehabilitate invaded ecosystems. The next few pages illustrate some of the work that scientists at the Rocky Mountain Research Station (RMRS) do to address the Forest Service vision for preventing and reducing impacts of invasive plant species.

Research Entomologist Sharlene Sing, RMRS Bozeman, shows people how to monitor their biocontrol releases.

Photo: USDA Forest Service.

In August 2013, the Forest Service published its National Strategic Framework for Invasive Species Management.

USDA Forest Service Vision

"The Forest Service will use the best available science-based methods to prevent and reduce the unacceptable impacts caused by invasive species and thereby sustain the integrity and resilience of the Nation's forest and grassland ecosystems."

– Forest Service National Invasive Species Strategic Framework

ABOVE: Cheatgrass intermixed with desert perennial plants at the Desert Research Natural Area of the Desert Experimental Range.

BELOW: Cheatgrass (in red), an invasive species, on the Desert Experimental Range.

Photos: Stanley Kitchen

Long-Term Experimental Areas Add Value for Studying Species Invasions

In February 1933, President Hubert Hoover set aside 87 Square miles of cold desert in western Utah "as an agricultural range experiment station." In time that station would become known as the Desert Experimental Range (DER). As was the case for many of the Forest Service's experimental forests and ranges, the DER location was selected to represent a prominent ecosystem under stress with expectations that the research conducted there would have broad application. During the decades that followed establishment, numerous agency and collaborating researchers have used short and long-term studies at the DER to meet that expectation, developing practices and principles now considered essential for sustainable management of North American cold-desert ecosystems.

More recently, an increased value for long-term experimental areas has been suggested by linking them into regional, continental or even global networks in order to address questions about changing landscapes resulting from species invasions, climate change and other stressors at broad spatial and ecological scales. For example, the DER is one of 23 experimental forests and ranges that use uniform methods to census native bee populations in a study designed to assess pollinator diversity and resilience across the country. The small effort required from any one experimental area to participate in this long-term monitoring program is small making it practical on tight budgets, but the collective potential for increasing knowledge is unique considering the scope of the study design.

"Long-term experimental sites have high value for addressing invasive species" says Stanley Kitchen, Scientist in Charge of the Desert Experimental Range. In a new study, temporal patterns of invasion by seven plant species were extracted from long-term vegetation records (41-86 years in length) at five long-term study sites in the western United States, including the DER. These patterns were compared to a logistic growth curve hypothesized to predict the progression of species invasion through phases of introduction, expansion and saturation. This idealized model was derived primarily from patterns of occurrence and abundance observed in historical records and herbarium samples. Observed patterns based upon the historic vegetation records were mostly more complex than those predicted, including sporadic spikes and crashes in abundance, rendering the logistic growth curve model unsuitable for predicting plant invasion patterns for these sites. Rather it appears that invasive plant occupation of arid rangeland environments may be subject to a complex suite of interacting drivers of vegetation change that vary through time and space. The article is titled "Using long-term datasets to study exotic plant invasions on rangelands in the western United States" and was published in the Journal of Arid Environments. In addition to exploring patterns of plant invasion, the article provides an honest assessment of the challenges and limitations inherent in the retroactive analysis and interpretation of historic data collected from different sites with variable objectives.

With the success of this and other studies involving the DER, Kitchen will continue exploring opportunities for addressing big-scale questions by leveraging data from the DER in multi-site collaborative networks.

Results of this study are published in:
Morris, C.; Morris, L. R.; Leffler, A. J.; Holifield Collins, C. D.; Forman, A. D.; Weltz, M. A.; Kitchen, S. G. 2013. Using long-term datasets to study exotic plant invasions on rangelands in the western United States. Journal of Arid Environments. 95: 65-74.
http://www.treesearch.fs.fed.us/pubs/43771

What Is an Invasive Species?

A species is considered to be invasive if it meets two criteria: (1) it is nonnative to the ecosystem under consideration, and (2) its introduction causes, or is likely to cause, economic or environmental harm or harm to human health (Executive Order 13112, 1999).

Forest Service Policy

The Forest Service is required by law, and regulations such as Executive Order 13112, to respond to invasive species that threaten terrestrial and aquatic resources of the National Forest System and to collaborate with Federal, State, and local partners to address invasive species that can spread from adjacent lands.

Biological Control: Preference, Performance and Confounding Influences

The closely-related invasive, exotic weeds Dalmatian toadflax, *Linaria dalmatica* (L.) P. Mill., and yellow toadflax, *L. vulgaris* Mill., successfully cross-pollinate and produce fertile, persistent infestations of hybrid (and back-cross) toadflax under field conditions in a number of western U.S. locations. Recent molecular evidence shows that in its European native range, *Mecinus janthinus*, a toadflax stem mining weevil intentionally introduced to North America for classical biological of both Dalmatian and yellow toadflax, is actually part of a species complex that includes *M. janthinis* Germar, 1812, associated with yellow toadflax, and the formerly cryptic species *M. janthiniformis* Toševski & Caldara spn., associated with Dalmatian toadflax.

A population of the Dalmatian toadflax associated weevil, *Mecinus janthiniformis*, has become established on a landscape scale invasion of hybrid toadflax in Palisades, ID. This discovery reveals that naturally occurring populations of hybrid toadflax can attract and successfully support at least one of the two introduced *Mecinus* species. Little is known about the linkage between preference and performance for either weevil species, although host plant leaf and floral volatiles usually play a key role in herbivore host selection. If hybridization alters the volatile profiles of host plants, then the fundamental way for insects to discern between non-hosts, suitable hosts and preferred hosts will also probably be affected. Will hybrids attract one weevil species over another, or will they be unattractive to both?

A Montana State University graduate student, Eli Hubbard, co-advised by MSU professor David Weaver and RMRS Research Entomologist Sharlene Sing, has been conducting research

ABOVE & BELOW: Montana State University graduate student Eli Hubbard conducts research on Mecinus *host selection.*

Photos: Sharlene Sing

to determine the intensity with which genotype-mediated mechanisms in toadflax plants influence host selection in two stem mining weevils, *M. janthinus* and *M. janthiniformis*. Initial volatile collections indicate differentiation of volatile production pattern for Dalmatian, yellow and hybrid toadflax.

The objectives of this study are to 1: establish if each *Mecinus* species will select its host plant over the other toadflax species based on responses to host plant odors, 2: establish if either biocontrol agent shows a preference for a particular hybrid cross based on its heritage, i.e. yellow toadflax as a maternal parent or Dalmatian as a maternal parent, and 3: to test the and reproductive potential of *Mecinus janthiniformis*, *M. janthinus* and *M. janthiniformis* obtained from the Palisades, ID site, in no-choice tests on both Dalmatian and yellow toadflax as well as laboratory and field collected hybrids.

Initial behavioral bioassays determined that only female weevils had a consistent response to host plant odors, while male subjects showed no preference for either control or host plant odors. In preliminary follow-up tests, female weevils of both species (*M. janthinus* and *M. janthiniformis*) and both *M. janthiniformis* biotypes (field collected from Dalmatian toadflax or hybrid toadflax) generally chose odors of their typical or source host plant species over control or alternative host species/biotype odors. Typical host plant species was similarly found to be the most viable host. *Mecinus janthiniformis* was fairly plastic in terms of host suitability and as such should be considered first for deployment against the highly variable forms of toadflax now being encountered in CO, ID, MT and WA forests and rangeland.

Cheatgrass common garden at the Brigham Young University Spanish Fork Farm near Provo, Utah. Multiple contrasting genotypes were planted together, and their seed progeny were genotyped using molecular markers to determine outcrossing levels.

Photo: Susan E. Meyer

Is All Cheatgrass Created Equal, or Are Some Cheatgrass Ecotypes More Equal than Others?

One of the remaining key questions in invasion ecology is how an exotic species, once established in its newly invaded range, is able to expand its distribution through secondary invasion into an array of different habitats. This question is especially relevant for *Bromus tectorum* (cheatgrass or downy brome), an invasive annual grass that now dominates several tens of millions of hectares of the western United States. This plant achieved wide distribution in the sagebrush steppe habitat within thirty years of its introduction in the late 1800's and has wreaked havoc in this ecosystem through its association with increased wildfire frequency and size. More recently, cheatgrass has come to the attention of land managers both in drier salt and warm desert ecosystems and in montane ecosystems such as ponderosa pine parkland.

Studies by Research Ecologist Susan E. Meyer (RMRS-GSD Provo) and her colleagues ask whether the recent success of cheatgrass in these formerly largely uninvaded ecosystems is more likely due to in situ evolution of ecotypes adapted to these novel environments or to arrival of preadapted ecotypes from another part of the native range in Eurasia. In order to rapidly evolve new ecotypes in situ in response to novel selection pressures, a species must possess sufficient genetic variation to act as a substrate for selection, and must also be able to undergo sexual recombination to generate new genotypes. Cheatgrass was known to be highly inbreeding, but outcrossing levels had never been adequately quantified, so its capacity for in situ evolution through sexual recombination was unknown.

To answer this question, Meyer and colleagues used molecular genetic markers (SSR or single sequence repeat and SNP or single nucleotide polymorphic markers) to examine the population genetic structure of cheatgrass in both experimental and wild populations. When widely differing genotypes were planted together in a common garden, the molecular fingerprints of their offspring indicated that $<$ 1% were the result of outcrossing. They obtained similarly low outcrossing levels in studies of four wild populations. Genetic diversity was relatively high in these wild populations, probably because they were derived from multiple introduction events.

One might expect low outcrossing levels to result in populations made up of multiple lineages of essentially identical individuals. The team did observe large groups of genetically identical individuals in these populations, but an equally common pattern was loosely branching groups of related individuals that appeared to represent descendants of past outcrossing events. This result, combined with relatively high genetic diversity, suggests that rapid in situ evolution may be possible. Large groups of identical individuals embedded within apparent family groups could represent genetic variants currently under positive selection, but this hypothesis would require further testing to confirm the presence of variation in adaptive traits.

The team also obtained evidence that some cheatgrass lineages are largely protected from outcrossing with cheatgrass of European origin in wild populations, forming large groups of identical individuals only distantly related to the rest of the population. These lineages are known to represent introductions from south-central Asia that are pre-adapted to thrive in warmer, more arid climates. One of these genotypes appears to be increasing in our study population on Cinder Cone Butte near Boise, Idaho. The presence of this genotype, and the dominance of its relatives in the Lahontan Basin of western Nevada and across the Mojave Desert, indicate that climate change in the region may favor these south-central Asian ecotypes, which are poised to invade larger areas and possibly displace cheatgrass of European origin as the climate warms.

Results of this study are published in:

Meyer SE, Ghimire S, Decker S, Merrill KR, and Coleman CE. 2013. The ghost of outcrossing past in downy brome, an inbreeding annual grass. Journal of Heredity 104:476-490. http://www.treesearch.fs.fed.us/pubs/43856

ABOVE: Mountain pine beetle outbreaks kill trees and open canopy allowing more light to reach the forest floor which helps promotes invasion by exotic plants.

FAR RIGHT TOP: Lamb's quarter invading Colorado study plots.

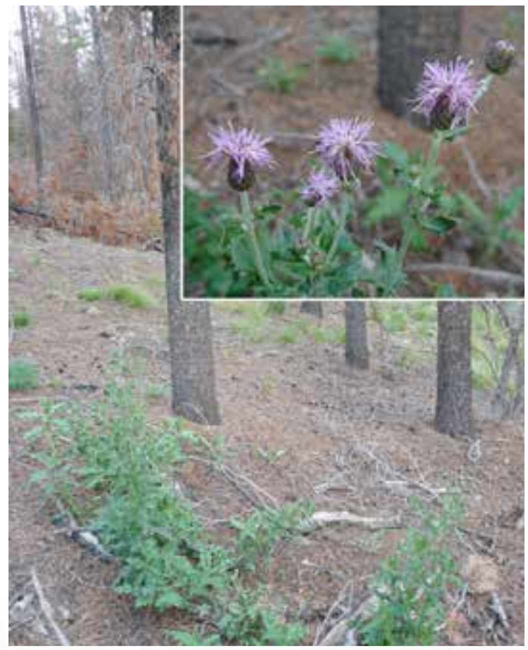
FAR RIGHT BOTTOM: Canada thistle invading Colorado study plots.

RIGHT LOWER: Examining invading bull thistles (Cirsium vulgare) *in a Colorado forest following a mountain pine beetle outbreak.*

Photos: Justin Runyon

Mountain Pine Beetle Outbreaks Affect Invasive Plants

Mountain pine beetles (MPB; *Dendroctonus ponderosae*) have altered millions of acres of western North American forests over the past decade. A potential unwanted, but often overlooked, side-effect of these outbreaks is invasion by nonnative plants. Any activity that creates disturbance can promote plant invasions by increasing resource availability (e.g. light) and/or decreasing plant competition. Mountain pine beetles create disturbance by killing trees which opens the canopy, and dead trees eventually fall exposing disturbed soil. If MPB outbreaks promote plant invasions, land managers need to be aware of this and armed with the knowledge to monitor and, if necessary, manage weeds following outbreaks. An ongoing study by Forest Service scientists seeks to answer these questions by quantifying the changes to forests following MPB outbreaks.



Invasive plants were monitored in twenty-five 0.2 acre plots in each of five states (CO, ID, MT, UT, WY) in predominately lodgepole pine stands with recent MPB-caused tree mortality (125 total plots). To date, invasion of exotic plants following MPB outbreaks has been minimal. However, according to Research Entomologist, Justin Runyon (RMRS-GSD, Bozeman) "in many plots trees are only now beginning to fall or be blown down – about six years after peak MPB activity – and early data suggest this disturbance may increase the abundance of invasive plants." For example, some plots in Colorado with numerous blown down trees are now being invaded by several invasive plant species (see photo). However, more research is needed and this study will continue to monitor invasive plants as more trees fall.

This is part of a collaborative project involving USDA Forest Service, Pacific Southwest Research Station (Chris Fettig), RMRS (José Negrón, Justin Runyon), and USDA Forest Service, Forest Health Protection (Steve Munson, Carl Jørgensen, Brytten Steed, Ken Gibson) entitled "Quantifying the short- and long-term impacts of mountain pine beetle outbreaks on forest fuels and other stand attributes in the Intermountain West". This project is funded, in part, by a Forest Health Monitoring-Evaluation Monitoring grant (INT-EM-F-10-03).

Benefits of Research: Management Collaboration

Collaborating with managers on applied biocontrol projects gives researchers an important opportunity to conduct experiments that verify or refute assumed treatment outcomes and can identify unanticipated but important ecological impacts resulting from weed treatments. Assuring that adequate monitoring will take place following vegetation treatments is an important way to provide support to land managers and ensure that NEPA requirements are being met.

Black-chinned hummingbird nests, built with downy cottonwood seeds, blend with pale Russian olive leaves.

Photo: D. Max Smith

Nonnative Plants: A Pro or Con for Riparian-nesting Birds?

Riparian woodlands, which support remarkable numbers of breeding birds, are highly vulnerable to invasion by nonnative woody plants. Saltcedar (*Tamarix ramosissima*), Russian olive (*Elaeagnus angustifolia*), and other invasive species are present throughout riparian habitats of the American Southwest, but flow regulation, urbanization, and other factors make some areas more prone to invasion than others. Despite the considerable amount of research conducted in riparian ecosystems, little is known about how nonnative plant invasions have affected populations of most riparian-nesting birds. By gathering information from multiple study sites, however, researchers can identify positive and negative responses of breeding birds to invasive plants.

Research cooperator Max Smith and GSD Program Manager Deborah Finch are comparing data collected during multi-year studies of riparian-nesting birds at the flow-regulated Middle Rio Grande in Central New Mexico and the free-flowing upper Gila River in southwestern New Mexico. They found that invasive species comprised less than 10% of woody plants at the Gila River and over 80% of plants at the Middle Rio Grande.

To determine how this variation influences breeding birds, Smith and Finch examined nest site selection and nesting success of Black-chinned Hummingbirds (*Archilochus alexandri*), one of the most abundant species in New Mexico riparian woodlands. At the Gila River, hummingbirds constructed over 70% their nests in native boxelder (*Acer negundo*) trees, and did not nest in nonnative trees or shrubs. At the Middle Rio Grande, the story was different, with over 60% of hummingbird nests constructed in Russian olive, salt cedar, or other nonnative species. Interestingly, nest success rates were higher in nonnative species at the Middle Rio Grande than in native species at the Gila River. "Our results show that, at least for this species, invaded forests remain productive breeding habitat", Smith says. "The reasons for higher success rates in nonnative species should be identified to help managers mitigate negative impacts of mechanical removal or biological control of these plants."

The investigators are also examining community-level responses of birds to invasive plants at these sites. Results will identify information gaps that must be addressed to ensure that riparian woodlands remain productive habitat for abundant species, such as the Black-chinned Hummingbird, and become more suitable for declining species, such as the Yellow-billed Cuckoo (*Coccyzus americanus*) and the Southwestern Willow Flycatcher (*Empidonax traillii extimus*). Results are in press in the journal, River Research and Applications.

News of Other Projects

"Toadflax: Biocontrol in Contrast to Herbicide in Elkhorn Mountains", a project proposed by RMRS Research Entomologist Sharlene Sing and Helena National Forest resource managers Mandy Alvino and Diane Johnson, was funded under the National Fish and Wildlife Foundation's Pulling Together: Managing Invasives program. The purpose of the project is to control toadflax species using integrated weed management combining inundative biocontrol releases with conventional herbicide treatments. High density releases of *Mecinus janthinus*, a stem boring weevil species that has been proven effective in managing Dalmatian and common toadflax, will be made over a two year period on four 200-400 acre areas and rigorously monitored to track the effectiveness of the treatment for five years. Herbicides will be applied to the same number of acres to provide a fair comparison of how these treatment strategies influence both target and nontarget plant populations. Recording baseline and post-treatment data will allow researchers to directly compare the influence of helicopter applied herbicide vs. biocontrol vs. no treatment option on health, productivity and biodiversity in rangeland plant communities. This effort includes local counties, state and federal agencies, private landowners, local conservation and implementation groups.

Releasing Mecinus *weevils on the Helena National Forest.*

Photo: USDA Forest Service.

Scouting for weed biocontrol release sites on the Helena National Forest.

Photo: USDA Forest Service.

Another project on the Helena National Forest, **"Cave Gulch Burned Area Biocontrol for Four Species of Weeds"**, is a Title II Project selected by the Missouri River RAC to be funded under the auspices of the 2008 - 2011 Secure Rural Schools Public Law 110-343. The goal of this project, to treat knapweed, Dalmatian and common toadflax, Canada thistle and leafy spurge with biocontrol insect agents, will also help assess the operational feasibility of increasing classical biological control of weeds. An inundative treatment strategy will be used for making high density releases of *Cyphocleonus achates* (knapweed), *Ceutorhynchus litura* (Canada thistle), *Mecinus janthinus* (toadflax) and *Aphthona* spp. flea beetles (leafy spurge). This strategy focuses on releasing thousands of insects against each target weed species in a 19,000 acre affected area, rather than treating at typically lower density recommended release rates. Prior to releasing biocontrol agents, Helena NF resource managers Andrew Hess, Diane Johnson and Mandy Alvino joined RMRS research entomologist Sharlene Sing to field validate the acres most appropriate to target for biocontrol.

Benefits of Biocontrol

Using host specific biocontrol insect agents eliminates the loss of non-target native forbs that usually are killed in a spray effort, creates a slow decline in the weeds and allows for a slow recovery of native forbs and grasses, and reduces erosion as the soil remains covered by vegetation while the insects are reducing the weed populations. This strategy reduces soil disturbance, bare soil, and the risk of other weeds invading while the target weed management efforts are accomplished.

Invasive Halogeton glomeratus *replaced native plants at a site on Desert Experimental Range previously occupied by shrubs.*

Photo: USDA Forest Service

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